Impacts of the Norway Rat on the auklet breeding colony at Sirius Point, Kiska Island, Alaska in 2003

Heather L. Major and Ian L. Jones

Correspondence to: Heather L. Major
Department of Biology
Memorial University of Newfoundland
St. John's, Newfoundland, A1B 3X9 CANADA

Phone: (709) 737-3239
FAX: (709) 737-3018
e-mail: x19hlm@mun.ca

> *"As with predator-prey relationships in general, the impact of alien predation is controlled by an interplay between a series of behavioral, ecological and geographical factors. The killing of birds is not automatically harmful to a population and it is often essential to distinguish between trivial depredations and those which threaten the stability or survival of a population. The distinction between the two situations does not necessarily depend on the scale of the losses: according to the circumstances, the killing of a few birds can be just as damaging as the killing of many. The critical point is whether the losses, whatever their size, consistently cause annual mortality to exceed annual recruitment."*
>
> *-Moors and Atkinson 1984*

The introduction of the Norway rat (*Rattus norvegicus*) onto Kiska Island, Aleutian Islands, Alaska, in the 1940s (Murie 1959) was an accident with impacts both widespread and negative. The flora and fauna of Kiska will continue to be subject to these impacts until rats are removed from this large remote island. In both 2001 and 2002 the Sirius Point Least and Crested Auklet colony appeared to be subjected to a particularly large impact from introduced rats. Rat predation on both Least and Crested Auklets was observed and the overall reproductive success of the Least Auklets was the lowest ever recorded for this species in the Aleutian Islands (Jones *et al.* 2001 and Major and Jones 2002). The primary objectives of this, the third year of the study, were to measure the impacts that the introduced rats are having on the auklet colony at Sirius Point and to investigate the biology and demography of the Norway rat population.

Moors and Atkinson (1984) suggested that although there are many factors that influence the severity of predation by invasive species one important factor is the size of the prey relative to that of the predator and the behavior of the prey (i.e. where they feed and nest). Burrow and crevice nesting seabirds are at a particular risk from Norway rats because the rats are a burrowing and ground feeding animal (Moors and Atkinson 1984). Least Auklets are more than 50% smaller in body size than adult Norway rats consequently adults, eggs and nestling are all vulnerable to predation. In order to measure the impacts of the Norway Rat on the Least and Crested Auklets breeding at the Sirius Point colony, interannual survival, reproductive success, chick growth and food quality and quantity brought back to the chicks has been measured and will be compared to that measured on Kasatochi and Buldir Islands, where there are no rats. In addition to this the biology of the rats was investigated through snap trapping, measuring, sexing and assessing the reproductive status of adult females.

Methods

Auklet productivity

Least and Crested Auklet breeding crevices were monitored for productivity using USFWS standardized procedures (Williams *et al.* 2002). If a crevice failed it was carefully checked for the cause of failure, including signs of rat predation. The productivity data from Kiska was then compared to that from Kasatochi and Buldir Islands, where there are no introduced rats, in order to determine the effects of the rats on the Sirius Point colony.

The three study plots established in 2001 were used for the productivity estimates in 2003 and are believed to be representative of the entire colony at Sirius Point (Jones et al. 2001). On the three productivity study plots, 208 Least and 20 Crested Auklet crevices were monitored.

Forty-one additional crevices, used for chick growth in 2002, were used in 2003 as a low disturbance plot and were monitored three times during the breeding season, once in early incubation and twice just before fledging. This plot was used to assess whether the frequent crevice checks and human induced disturbance might have a negative impact on the outcome of the productivity crevices at Sirius Point.

Least Auklet chick growth

To evaluate if the nutritional requirements of the chicks on Kiska are being met and are similar to those on Kasatochi Island, chick growth was monitored during the 2003 breeding season. Chicks were measured once every four days from hatching until fledging in 40 crevices found near the end of incubation. Once a chick was found in a crevice it's age was estimated, if it was wet it is presumed to be 1 day; dry but wobbly, 2 days; and dry, alert and coordinated, 3+ days. Measurements of mass, tarsus length, and wing length were taken and were compared to similar measurements of Least Auklets from other colonies. When a chick was found dead similar measurements were taken and the crevice and chick were examined closely to determine the cause of death.

To determine whether the food being brought to the Least Auklet chicks on Kiska is similar in quantity and quality to that being brought back to the chicks on Buldir and Kasatochi Islands food sampling was carried out during chick rearing using USFWS standard protocols (Williams *et al*. 2002)

Auklet survival and banding

The adult interannual survival of Least and Crested Auklets was measured using field procedures developed by Jones (1992) and the MARK (White and Burnham 1999) analysis program. Resightings of Least and Crested Auklets banded during the 2001 field season were regularly carried out from the blind during the daily activity periods throughout the entire breeding season (May through August 2003). Using noose carpets set out on the colony surface within a single 50 m^2 plot Least and Crested Auklets were captured during June and July. Noose carpets are believed to select breeding and non-breeding auklets randomly from the population (Jones 1992). Each captured auklet was given a numbered stainless steel leg band and adults were also given a unique combination of three plastic color bands. When a bird was caught measurements were taken according to the standard protocols (Jones and Montgomerie 1992, Jones 1993a, Jones et al. 2000).

Norway Rat feeding ecology and distribution

Liver and pectoral muscle tissue of ten Norway Rats killed with snap traps, at both the colony and the Lake District during early June and again in late July and early August, were sampled. The samples were dried for three hours at 60° Celsius and stored in o-ring vials for stable isotope analysis. In addition, all Norway Rats caught throughout the auklet breeding season were measured (mass, body length, and total length), sexed and the reproductive status of the females was assessed. We also searched for rat caches of prey items anytime we were hiking in and around the colony as well as any rat sign found elsewhere on the island. When a cache was found its location, number of individuals and type of organism cached (i.e. adult auklet, egg) was recorded. Throughout the season we recorded our observations of rat sign (trails, fresh droppings, predated adults, eggs, and juvenile auklets) and using this information have updated the 2002 map of rat distribution around the northern parts of Kiska Island.

Results and Discussion

Auklet productivity

In 2003, Least Auklet hatching success was 0.76 on the New Lava, 0.83 on Old Lava low, and 0.90 on Old Lava high (Table 1), the hatching success on the three productivity plots did not differ significantly (χ^2=4.6, df=2, p-value=0.1). Overall hatching success on Kiska in 2003 was 0.82, which is significantly different than the hatching success on Kiska in 2002, which was 0.64 (χ^2=18.3, df=1, p-value<0.001), but not significantly different from the 0.77 observed in 2001 (χ^2=2.3, df=1, p-value= 0.1; Jones *et al.* 2001 and Major and Jones 2002). The majority of crevices that did not hatch were the result of the egg being abandoned (n=19, or 50% of crevices that failed during incubation) and the egg disappearing without a trace (n=9, or 23% of crevices that failed during incubation). Prior to hatching, four eggs were visibly predated by a rat and 2 eggs were rat predated late in the season (after hatching) after they had been abandoned. In these cases the egg was chewed open on one side and either the inside of the egg was licked clean or a mature dead embryo was found inside the broken egg.

Least Auklet fledging success was 0.66 on the New Lava, 0.58 on Old Lava low, and 0.58 on Old Lava high in 2003 (Table 1), the fledging success on the three plots did not differ significantly (χ^2=1.1, df=2, p-value=0.6). Most of the crevices that failed prior to fledging were the cause of the chick disappearing without a trace (n=41, or 62% of the crevices that failed prior to fledging). The second leading cause of crevice failure during this stage was the result of the chick being found dead in the crevice (n=25, or 38% of the crevices that failed prior to fledging), only five (8% of the crevices that failed prior to fledging) of these dead chicks were found to have been injured. Fledging success on Kiska was 0.61, which was significantly higher (χ^2=95.6, df=2, p-value=<0.001) than the 0.18 and 0.16 found in 2001 and 2002 (Jones *et al.* 2001, Major and Jones 2002).

Overall reproductive success was 0.50 on the New Lava, 0.48 on Old Lava Low and 0.52 on Old Lava High (Table 1), there was no significant difference between the overall reproductive success (χ^2=0.1, df=2, p-value=0.9) on the three plots in 2003. Least Auklet overall reproductive success was 0.50 in 2003, significantly higher (χ^2=111.7, df=2, p-value<0.001) than the 0.13 and 0.10 measured in 2001 and 2002. The largest difference in overall reproductive success in the years 2001-2003 was the result of chick loss, with greater than 50% of the chicks dying in 2001 and 2002 and 20-30% of the chicks in 2003 dying or disappearing prior to fledging (Figure 1).

The pattern of auklet reproductive performance at Kiska during 2001-2003 is consistent with both a localized food shortage around the Sirius Point colony and also with predation and disturbance by the Norway rat. If the years 2001-2002 were really years of poor food availability, the high number of dead chicks that were found would be explained by adults leaving the colony for unusually long periods to search for food farther away, reduced chick brooding and provisioning, resulting in inexperienced and poor condition birds failing (Ashmole 1963) – the food shortage hypothesis. On the other hand, the large number of dead chicks could also be explained by disturbance and predation by rats, also resulting in reduced chick brooding and provisioning. If there was indeed a decreased number of rats near Sirius Point in 2003, the difference in the breeding success of the auklets on Kiska between years may have been the result of a decreased amount of predation in 2003 compared with 2001 and 2002 – the rat predation hypothesis. Moreover, a cumulative impact of both rats and low food availability may have been the cause of the extremely low reproductive success at Sirius Point in 2001 and 2002. In 2001 the numbers of sub-adults on the banding plot was large (Jones et al. 2001), while in both 2002 and 2003 there were relatively few sub-adults on the plot. This suggests that in 2000 the reproductive success may have been similar to that recorded in 2003, further evidence for extreme fluctuation in productivity across years at Kiska.

In 2003, Least Auklet hatching, fledging and overall reproductive success at Buldir were 0.90, 0.37 and 0.34 (Jones *et al.* 2003; Table 2); and on Kasatochi were 0.86, 0.84 and 0.73 (Barton and Lindquist 2003; Table 2). Hatching success on Kiska in 2003 was not significantly different than that measured on Kasatochi in 2003 but was significantly higher than that measured on Buldir in 2003 (Table 3). Fledging and overall reproductive success at Kiska in 2003 was significantly different (Table 3) than measured on both Buldir (lower) and Kasatochi (higher) Islands in 2003.

Least Auklet reproductive success at Sirius Point in 2003 was seemingly anomalous, as was the reproductive success among the other two Aleutian auklet colonies monitored. However, the overall reproductive success on Kasatochi varied significantly among the years 1996-2002 (χ^2=13.5, df=7, p-value=0.04). When solely comparing those years when reproductive success was highest on Kasatochi (1996, 2000 and 2003) there were no significant differences (χ^2=1.0, df=2, p-value=0.6), suggesting that 2003 is not actually an anomaly. On Buldir Island there was no significant variation in reproductive success among the years 1996-2002 (χ^2=6.2, df=5, p-

value=0.3), but there was a significant difference between these years and 2003 (χ^2=17.6, df=6, p-value=0.007). As with Kasatochi, when you compare the reproductive success from Buldir in 2003 with those years when the reproductive success was at it's lowest (1990, 1994, 1998, and 2003) there is no significant difference (χ^2=2.130, df=3, p-value=0.546) among these years, again suggesting that the reproductive success on Buldir in 2003 was not an anomaly. In 2003 Least Auklets on the low disturbance plot on Kiska, had on overall reproductive success of 0.63 (Table 3). The crevices in this plot were checked three times during the auklet breeding season, once during early incubation and twice in late chick growth. The overall reproductive success was significantly higher (χ^2=4.4, df=1, p-value=0.04), on the low disturbance plot than on the Kiska productivity plots in 2003. The crevices on this plot were all located in an area that was not entered or hiked through throughout the entire breeding season, except for the three monitoring dates. The low disturbance crevices were used as the chick growth crevices in 2002 and the overall reproductive success on this plot in 2002 was not significantly different than the New Lava productivity plot in 2002 (Major and Jones 2002). Similar to human disturbance experiments on St. Lawrence Island, where it was found that human disturbance led to a lower breeding success on disturbed plots over control plots (Piatt *et al.* 1990) we found that on Kiska in 2003 Least Auklets had a lower overall reproductive success on the disturbed productivity plots than the low disturbance plot (Table 3). It was hypothesized in 2002 that if the auklets on Kiska are ultra sensitive to disturbance because of the presence of rats, than human disturbance may be causing higher reproductive failure on Kiska than other islands that do not have rats and this added sensitivity. Piatt *et al.* (1990) found that in the control plots the Least Auklets did 25.5% better than in the disturbed plots, on Kiska in 2003 the Least Auklet did 28.6% better in the low disturbance plot than in the productivity plots. This suggests that even though the auklets on Kiska are sensitive to human disturbance, they are not more sensitive than at other colonies.

Crested Auklet hatching success was 0.00 on the New Lava, 0.88 on the Old Lava Low and 0.78 on the Old Lava High plot (Table 5). Fledging success was 0.00 on the New Lava, 0.71 on the Old Lava Low and 0.57 on the Old Lava High plot (Table 5). Overall reproductive success was 0.00 on the New Lava, 0.62 on the Old Lava Low and 0.44 on the Old Lava High (Table 5). Crested Auklet hatching, fledging and overall reproductive success were not significantly different on Kiska among 2001, 2002 and 2003 (hatching success: χ^2=1.0, df=2, p-value=0.6;

fledging success: χ^2=0.7, df=2, p-value=0.7; and overall reproductive success: χ^2=0.2, df=2, p-value=0. 9). In 2003, hatching, fledging and overall reproductive success for Crested Auklets were 0.78, 0.14 and 0.11 on Buldir (Jones *et al.* 2003; Table 5), 0.88, 0.72 and 0.63 on Kasatochi (Barton and Lindquist 2003; Table 4). Hatching success was significantly different on Kiska than on Kasatochi in 2003 but was not significantly different on Kiska than Buldir in 2003 (Table 4). Fledging success was not significantly different between Kiska and Kasatochi Islands in 2003 but was significantly higher on Kiska Island than on Buldir Island (Table 4). Overall reproductive success at Kiska was not significantly different than that measured on Kasatochi Island but was significantly higher than that on Buldir Island in 2003 (Table 4).

Overall reproductive success of Crested Auklets on Kiska and Kasatochi Islands did not differ significantly in 2003 while Buldir Island was significantly lower than both of them. This suggests that although there may be large-scale trends that influence auklet reproductive success across the Aleutians, there can be striking variations between colonies.

Least Auklet chick growth

Out of a total of 40 crevices that were found at the late stages of incubation on the New Lava Dome, 18 (54% of the chicks that hatched) Least Auklet chicks made it to fledging (Table 1). Fledging success of the chick growth crevices was 0.54, this is the result of 11 (28% of the total number of crevices) dead chicks found in the crevices with no apparent injuries (Table 1). The overall reproductive success of the Least Auklets in the chick growth crevices was 0.45, which was not significantly different from the overall reproductive success on the Kiska productivity plots (χ^2=0.3, df=1, p-value= 0.6) in 2003.

Least Auklet chicks have been shown by Piatt *et al.* (1990) and Roby and Brink (1986) to on average increase rapidly in mass over the first 20 days and on average have a body mass between 100-108% of the mean adult body mass at the time of fledging. On Kiska in 2003 we also found that the chicks increased in mass rapidly until approximately day 20 (Figure 2). Least Auklets fledge when they are approximately 25 days old, and should be at or above adult body mass at this time (Jones 1993b). Mean adult Least Auklet body mass, as measured on the banding plot in 2001-2003, on Kiska was 81.5g (standard deviation of 5.7, n=283), in 2003 the Least Auklet chicks fledged at a mean body mass of 73.2g (standard deviation of 9.8, n=11), or 90% of the

mean adult body mass. However, fledging body mass on Kiska in 2003 was not significantly different (p-value=0.3) than adult body mass on Kiska.

Wing chord length has been found to increase steadily throughout the nestling stage and is at or near the adult wing length at the time of fledging (Jones 1993b), as was measured on Kiska in 2003 (Figure 3). Mean adult Least Auklet wing chord length on Kiska, as measured on the banding plot 2001-2003, was 98 mm (standard deviation 2.3, n=283) in 2003 the Least Auklet chicks fledged with a mean wing chord length of 83.5mm (standard deviation 6.8, n=11), or 85% of the mean adult wing chord length. Fledging wing chord length on Kiska in 2003 was significantly smaller (p-value=0.025) than adult wing chord length on Kiska.

Tarsus length grew steadily on Kiska in 2003 until the chicks reached approximately 20 days of age at which time it leveled off (Figure 4). Mean adult tarsus length on Kiska, as measured on the banding plot in 2001-2003, was 20.4 mm (standard deviation 0.96, n=283), in 2003 the Least Auklet chicks fledged with a mean tarsus length of 18.7mm (standard deviation 0.64, n=4), or 92% of the adult mean tarsus length. Fledging tarsus length on Kiska in 2003 was significantly smaller (p-value=0.062) than adult tarsus length on Kiska.

Auklet adult survival and banding

Intensive banding on Kiska was not carried out in 2003 but we did catch 26 Least Auklets, 13 of which were new adults, and seven new Crested Auklet adults (Table 6). We used the program MARK (White and Burnham 1999) to estimate adult interannual survival the model with the best fit incorporated the year, and the sex of the bird (3 groups: male, female and unknown; Table 7). Applying this model, the best estimate of adult interannual survival on Kiska from 2001-2002 was 88.3%, and from 2002-2003 was 98.6% (Table 8). Least Auklet survival is variable across years in the Aleutians (Figure 5) but there were no significant differences (p-value=0.2) between Buldir, Kasatochi and Kiska Islands in 2001 - 2003. The survival estimates for Kiska only take into account the overwinter survival for 2001-2002 because the birds were banded in late June and July in 2001, by this time the impacts of rat predation would be lessened because once the chicks hatch in late June adults do not remain in the crevices for long. Furthermore, because of the low reproductive success of the Least Auklets on Kiska in 2001 and 2002 a high number of the adult breeders experienced breeding failure and would have left the colony and would not have been subjected to predation by rats while incubating and brooding their chick. However,

the 2003 survival estimate does suggest that Least Auklets on Kiska are not subject to higher overwinter mortality than either Buldir or Kasatochi. The estimate of 98.6% for 2002-2003 is not backed up by a subsequent year of resighting but was very high nonetheless, and suggests there was not unusual mortality during this period at the colony or at sea.

Norway Rat feeding ecology and distribution

Appendix 1 contains the list of species, tissues and sampling locations used in 2003 for the proposed stable isotope analysis.

Adult Norway Rats can range in weight between 150-300 g with few weighing more than 400 g (Moors 1990). Similar to 2002, rats that were caught in 2003 near the Sirius Point auklet colony and at the Kiska Lake District ranged in size from 32 g to 419 g (Figure 6) with the average weight being 170 g. Olds and Olds (1979) reported that when sexually mature, Norway rats normally have an overall length between 37-60cm. Again in both 2002 and 2003, rats caught at Kiska ranged from 18.4 cm to 47 cm (Figure 6) with the average overall length being 31.6 cm.

Norway rat sign seemed to be lower than seen in previous years early in the breeding season in 2003, but by the middle of the season rat sign abundance seemed to be similar to that observed in 2002. In addition to this, direct evidence of Norway Rat predation in the productivity crevices was increased in 2003 over 2001 but was not different in 2003 over 2002. Rat sign was also found in 2003 at elevations above 500 feet (higher than in both 2001 and 2002; Figure 7). Norway Rats were very abundant during both our trips to the Lake District in 2003.

Other observations

A summary of Norway rat sign (droppings, dead auklets with chewed brains) found during the 2003 field season is attached in Appendix 2.

A list of bird species identified during fieldwork in 2003 is attached in Appendix 3.

Conclusions

Considering that the Sirius Point auklet colony is one of the largest seabird colonies in Alaska it is important to understand and mitigate any negative impacts that introduced Norway

rats may have on the colony. As in 2001 and 2002 the impact of Norway rats on the Least and Crested Auklet colony at Sirius Point in 2003 was again difficult to assess. Contrary to the two previous years, in 2003 the overall reproductive success of the Least Auklets on Kiska was close to average for Aleutian auklet colonies, at 0.5 (Jones 1993b), and chick growth appeared to be close to normal in 2003, whereas in 2002 chicks grew very slowly and were approximately half the size of an adult at the time of fledging (Major and Jones 2002).

Two hypotheses to explain why the overall reproductive success on Kiska was so dramatically improved in 2003 are 1) there was a decreased rate of Norway Rat predation in 2003 compared to 2002 and 2001, and 2) a local food shortage caused by the large size of the colony and locally poor oceanographic conditions resulted in the near reproductive failure in 2001 and 2002, but improving conditions provided more food and allowed higher reproductive success in 2003 (Table 9). Neither of these hypothesis can be definitively rejected or accepted based on the information we have available (Table 9). Although Kiska experienced the lowest overall reproductive rate ever recorded for this species in the Aleutians in 2002 (Major and Jones 2002) and Kiska is the only island with a monitoring program that has introduced rats, direct evidence of rat predation causing the low productivity was elusive. Similarly, there was no certain evidence that the improvement in reproductive success in 2003 related to lessened rat predation, or even that there were less rats present near the colony in 2003. There is no quantitative information concerning the abundance of food available and the location used for feeding by the Least Auklets near the Sirius Point colony compared to the other auklet colonies. Despite the lack of a definitive answer about the relative impact of rats and other factors affecting auklets, our data collected on Kiska are crucial for achieving the long-term aim of assessing the impact the introduced rats on the auklet colony and how other factors might affect the behavior and reproductive success of the auklets that breed there.

Recommendations

1. Monitoring of the productivity and survival of auklets needs to be continued in order to get reliable estimates of breeding success and adult survival and to account for variability across years.
2. Monitoring of rat activity and demography on Kiska Island needs to be continued and expanded to further understand the impacts of this predator on auklets and the ecology of the island. This urgently needs to be made more quantitative by developing a protocol for estimating seasonal and annual variation in rat abundance.
3. Monitoring of the food being delivered to auklet chicks needs to be continued in order to assess whether the quantity and quality of the food is similar to that on Buldir and Kasatochi Islands in years of low reproductive success on Kiska.
4. The number of sub-adults on the banding plot should be recorded (during resighting) as an additional index of auklet reproductive success on Kiska.
5. A study of the relationships among food abundance and distribution with auklet reproductive success and foraging locations is urgently needed for Kiska and nearby auklet colonies.

References

Ashmole, N.P. 1963. The regulation of numbers of tropical oceanic birds. Ibis 103b: 458-473.

Barton, D.C., and K.E. Lindquist. 2003. Biological monitoring in the central Aleutian Islands, Alaska in 2003; summary appendices. U.S. Fish and Wildlife Serv. Rep., ANMWR 03/12. Adak, Alaska 105pp.

Jones, I.L. 1992. Factors affecting survivorship of least auklets (*Aethia pusilla*) at St. Paul Island, Alaska. Auk. 109: 576-584.

Jones, I.L. 1993a. Sexual differences in bill shape and external measurements of Crested Auklets *Aethia cristatella*. Wilson Bulletin 105: 525-529.

Jones, I.L. 1993b. Least Auklet (*Aethia pusilla*). *In* The Birds of North America, No. 69 (A. Poole and F. Gill, Eds.). Philadelphia: The Academy of Natural Sciences; Washington, D.C.: The American Ornithologists' Union.

Jones, I.L. and R.D. Montgomerie. 1992. Least Auklet ornaments: Do they function as quality indicators? Behav. Ecol. Sociobiol. 30: 43-52.

Jones, I.L., F.M. Hunter, and G. Fraser. 2000. Patterns of variation in ornaments of Crested Auklets (*Aethia cristatella*). Journal of Avian Biology 31: 119-127.

Jones, I.L., C. Gray, J. Dussurault., and A.L. Sowls. 2001. Auklet demography and Norway Rat abundance and distribution at Sirius Point, Kiska Island, Alaska in 2001. Unpublished report for the U.S. Fish and Wildlife Service.

Jones, N., M. Murphy, et al. 2003. Biological monitoring at Buldir Island, Alaska in 2003; Summary appendices. U.S. Fish and Wildl. Serv. Rep. AMNWR 03/XX. Homer, Alaska. XXXpp.

Major, H.L. and I.L. Jones. 2002. Impacts of the Norway Rat on the auklet breeding colony at Sirius Point, Kiska Island, Alaska, 2002. Unpublished report for the U.S. Fish and Wildlife Service.

Moors, P.J. 1990. Norway rat. *In*: The handbook of New Zealand mammals. (King, C.M., Ed.) Oxford University Press, Aukland. pp. 192-206.

Moors, P.J. and I.A.E. Atkinson. 1984. Predation on seabirds by introduced animals, and factors affecting its severity. ICBP Tech. Publ. No. 2: 667-690.

Murie, O.J. 1959. Fauna of the Aleutian Islands and Alaska Peninsula. North American Fauna, Volume 61, U.S. Fish and Wildlife Service.

Olds, R.J. and J.R. Olds. 1979. A colour atlas of the rat dissection guide. Wolfe Medical Public. Ltd. Italy.

Piatt, J.F., B.D. Roberts, W.W. Lidster, J.L. Wells, S.A. Hatch. 1990. Effects of human disturbance on breeding Least and Crested Auklets at St. Lawrence Island, Alaska. Auk 107: 342-350.

Roby, D.D. and K.L. Brink. 1986. Breeding biology of least auklets on the Pribilof Islands, Alaska. Condor 88: 336-346.

Williams, J.C., L. Scharf, and G.V. Byrd. 2002. Ecological monitoring methods of the Aleutian Islands Unit, Alaska Maritime National Wildlife Refuge – revised edition 2. U.S. Fish and Wildl. Serv. Rep., ANMWR 00/01. Adak, Alaska. 351pp.

White, G.C. and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46 Supplement, 120-138.

Table 1 Least Auklet productivity and known causes of breeding failure at Kiska Island in 2003.

	Lava Dome	Old Lava low	Old Lava high	Total	Chick Growth
Crevices monitored, n (a)	96	54	58	208	40
Number hatched (b)	73	45	52	170	33
Egg abandoned	10	4	5	19	4
Egg disappeared	5	4	0	9	1
Egg broken	1	0	0	1	1
Egg predated	4	0	0	4	1
Egg abandoned and predated	2	0	0	2	0
Crevice collapsed	0	1	0	1	0
Dead adult in crevice	1	0	1	2	0
Number fledged (c)	48	26	30	104	18
Small dead chick	6	1	6	13	9
Chick disappeared	17	12	12	41	4
Small dead chick, injured	1	1	3	5	0
Dead chick	1	5	1	7	2
Hatching success (b/a)%	0.76	0.83	0.90	0.82	0.82
Fledging success (c/b)%	0.66	0.58	0.58	0.61	0.54
Reproductive success (c/a)%	0.50	0.48	0.52	0.50	0.45

Table 2 Least Auklet productivity at Kiska, Buldir and Kasatochi Islands in 2003

	Kiska dome	old low	old high	Kiska Total	Buldir[1]	Kasatochi[2]
n(a)	96	54	58	208	83	110
Number hatched (b)	73	45	52	170	75	95
Number fledged (c)	48	26	30	104	28	80
Hatching success (b/a)	0.76	0.83	0.90	0.82	0.90	0.86
Fledging success (c/b)	0.66	0.58	0.58	0.61	0.37	0.84
Reproductive success (c/a)	0.50	0.48	0.52	0.50	0.34	0.73

[1]Jones *et al*. 2003

[2] Barton and Lindquist 2003

Table 3 Least Auklet productivity in the low disturbance plot and the total productivity on Kiska using only the data from the same three crevice checks in 2003.

	Low disturbance	Kiska total
Crevices monitored, n(a)	41	207
Number hatched (b)	39	183
Egg abandoned	2	21
Egg broken	0	3
Number fledged (c)	26	94
Chick disappeared	10	25
Dead chick	0	9
Unknown crevice failure	3	55
Hatching success (b/a)	0.95	0.88
Fledging success (c/b)	0.67	0.51
Reproductive success (c/a)	0.63	0.45

Table 4 Chi-square tests for statistical differences in hatching, fledging and overall reproductive success between, Kiska, Buldir and Kasatochi Islands for Least (LeAu) and Crested (CrAu) auklets.

Species		Hatching Success			Fledging Success			Reproductive Success		
		χ^2	df	p-value	χ^2	df	p-value	χ^2	df	p-value
LeAu	Kiska – Buldir	3.320	1	0.068	11.909	1	<0.0001	6.332	1	0.012
	Kiska – Kasatochi	1.112	1	0.292	15.235	1	<0.0001	15.242	1	<0.0001
CrAu	Kiska – Buldir	0.451	1	0.502	12.250	1	<0.0001	9.410	1	0.002
	Kiska – Kasatochi	4.786	1	0.029	0.331	1	0.565	2.435	1	0.119

Table 5 Crested Auklet productivity at Kiska, Buldir and Kasatochi Islands in 2003.

	Kiska dome	old low	old high	Kiska All	Buldir[1]	Kasatochi[2]
n(a)	3	8	9	20	45	136
Number hatched (b)	0	7	7	14	35	120
Number fledged (c)	0	5	4	9	5	86
Hatching success (b/a)	0.00	0.88	0.78	0.70	0.78	0.88
Fledging success (c/b)	0.00	0.71	0.57	0.64	0.14	0.72
Reproductive success (c/a)	0.00	0.62	0.44	0.45	0.11	0.63

[1]Jones *et al*. 2003

[2] Barton and Lindquist 2003

Table 6 Auklet banding at Sirius Point, Kiska Island in 2003.

Date	Least Auklet				Crested Auklet				**Day**
	Adults	Sub-adults	Retraps	Total	Adults	Sub-adults	Retraps	Total	**Total**
June 28	4		4	8	3			3	**11**
June 29	2		1	3	3			3	**6**
July 2	7		8	15	1			1	**16**
Total	**13**		**13**	**26**	**7**			**7**	**33**

Table 7 Comparison of the ten best survival-recapture models for Least Auklets on Kiska Island in 2001-2003, in order of decreasing fit, where φ is survival, p is the recapture probability, t is time, and g is group (male, female and unknown)

Model	AICc	Δ AICc	AICc Weight	# Parameters	Deviance
$\{\varphi_t\ p_g\}$	320.096	0.00	0.27819	5	4.220
$\{\varphi_t\ p_.\}$	321.298	1.20	0.15252	3	9.519
$\{\varphi_t\ p_t\}$	321.298	1.20	0.15252	3	9.519
$\{\varphi_t\ p_{g*t}\}$	321.587	1.49	0.13200	7	1.570
$\{\varphi_.\ P_t\}$	323.074	2.98	0.06276	3	11.294
$\{\varphi_g\ p_t\}$	323.456	3.36	0.05185	5	7.579
$\{\varphi_{g*t}\ p_t\}$	324.010	3.91	0.03930	7	3.993
$\{\varphi_{g*t}\ p_.\}$	324.272	4.18	0.03448	7	4.255
$\{\varphi_{g*t}\ p_{g*t}\}$	324.729	4.63	0.02743	9	0.526
$\{\varphi_{g*t}\ p_g\}$	325.132	5.04	0.02243	9	0.929

Table 8 Least Auklet survival estimate for 2001-2003 as determined by best-fitting model: $\{\varphi_t\ p_g\}$ from the Program MARK, where φ is survival, p is the recapture probability, t is time, and g is group (male, female and unknown).

Parameter	Estimate	Standard Error	95% Confidence Interval Lower	Upper
1:φ 2001-2002	0.883	0.023	0.828	0.922
2:φ 2002-2003	0.986	0.025	0.647	1.00
3:p females	0.918	0.029	0.842	0.959
4:p males	0.974	0.017	0.907	0.993
5:p unknown sex	0.902	0.043	0.780	0.960

Table 9 Summary of 'evidence' supporting and contradicting the rat and food-abundance hypotheses to explain variation in auklet breeding success at Sirius Point, Kiska Island.

Rat hypothesis
supporting
Extreme low productivity in 2001 and 2002 only at Kiska, the only island with rats
Large numbers of rat predated adults, eggs and chicks found at Kiska
Possibly reduced numbers of rats early in 2003, the year of increased productivity
contradicting
Low numbers of confirmed rat-predated eggs and chicks in productivity monitoring crevices
High productivity in 2003 even though some rats were present at Sirius Point
Low productivity may sometimes occur at colonies without rats (e.g. Buldir, 2003, Crested Auklets).
Food-abundance hypothesis
supporting
Many small chicks died in 2001 and 2002, without signs of predation or injury
Poor chick growth in 2002, when productivity was low
Improved chick growth in 2003, when productivity was high
Kiska is by far the largest auklet colony, therefore competition for food should be intense, explaining low productivity relative to other colonies
contradicting
Productivity at Buldir and Kasatochi was normal in 2001 and 2002, so there is no evidence for concurrent breeding failure across colonies that would be brought on by a large-scale food shortage
There is no well-described mechanism for a two year local food shortage at one colony while the nearby colony has normal productivity
Oceanic productivity indices (North Pacific Index, Aleutian Low Pressure Index, Pacific Decadal Oscillation Index) were not extraordinarily anomalous in 2001 and 2002, inconsistent with oceanography as a cause for reduced auklet productivity at Kiska in those years

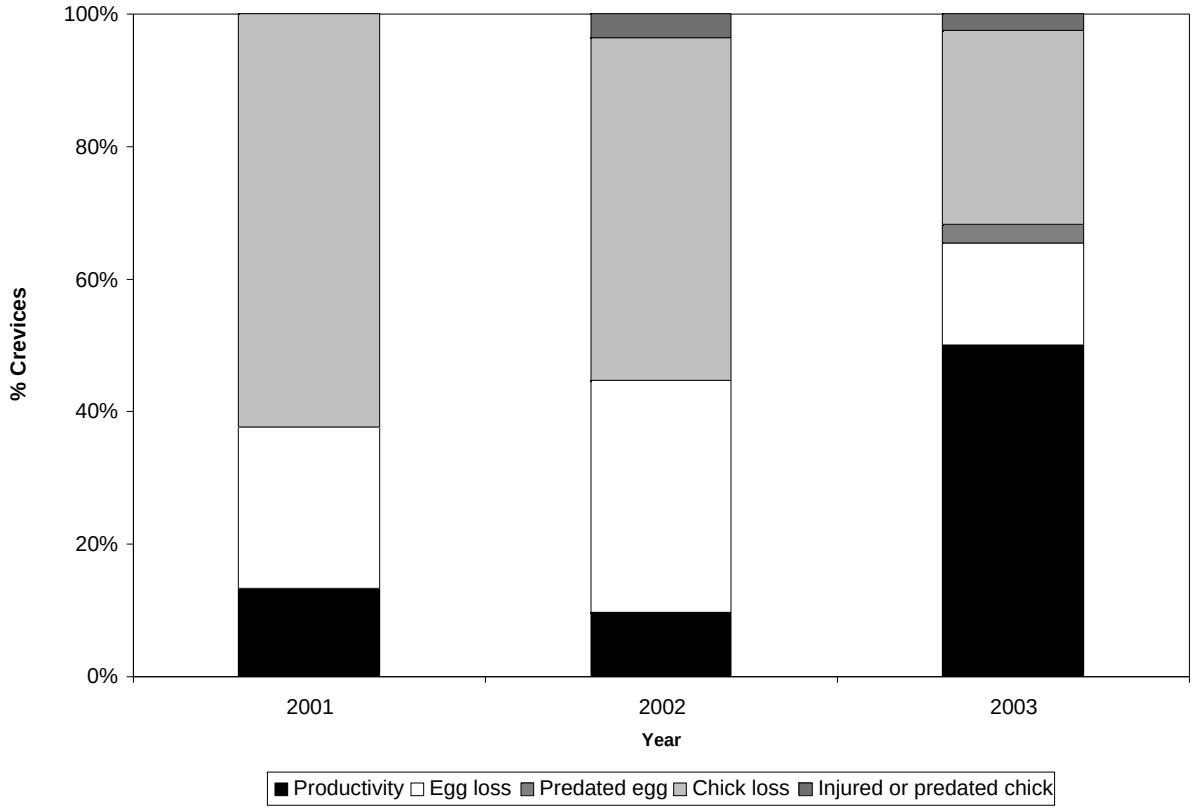

Figure 1 Reproductive performance of Least Auklets on Kiska Island in 2001-2003.

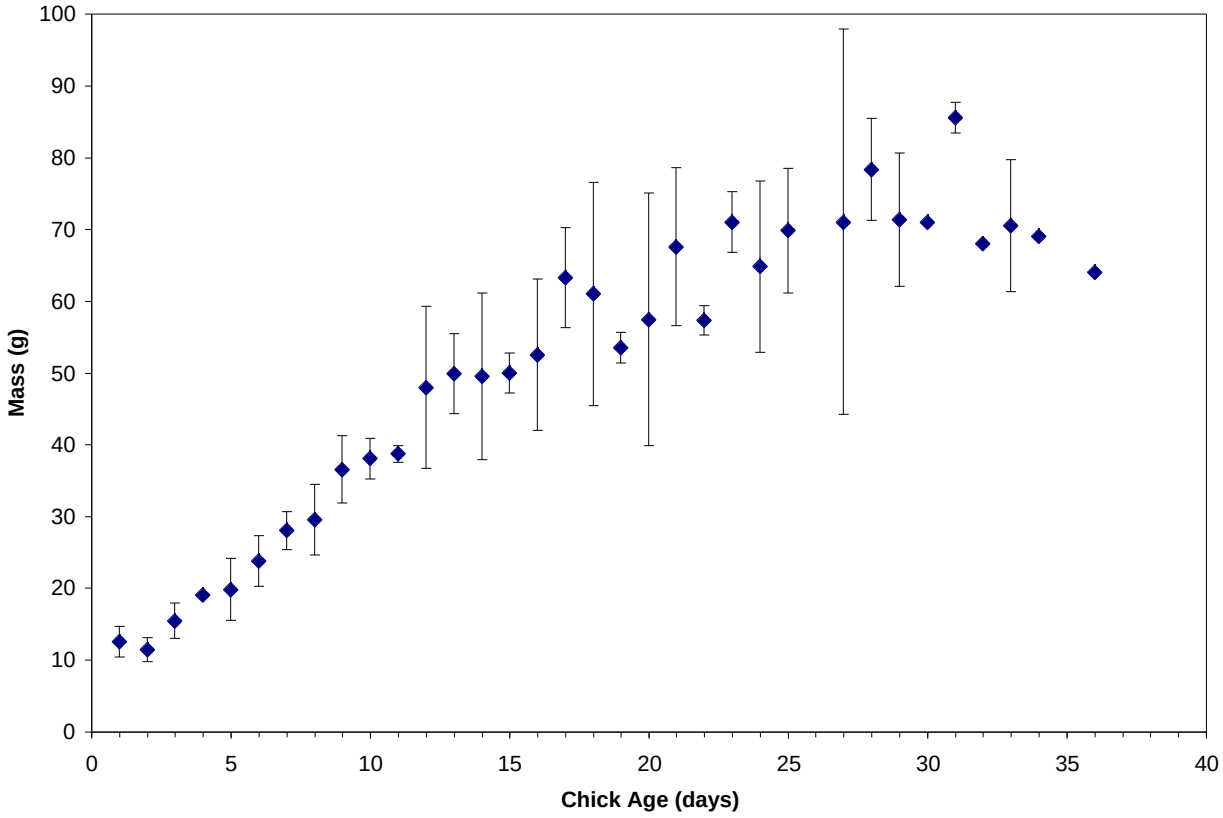

Figure 2 Increase in mass of Least Auklet chicks over the nestling stage at Sirius Point in 2003, values are the mean with one standard deviation.

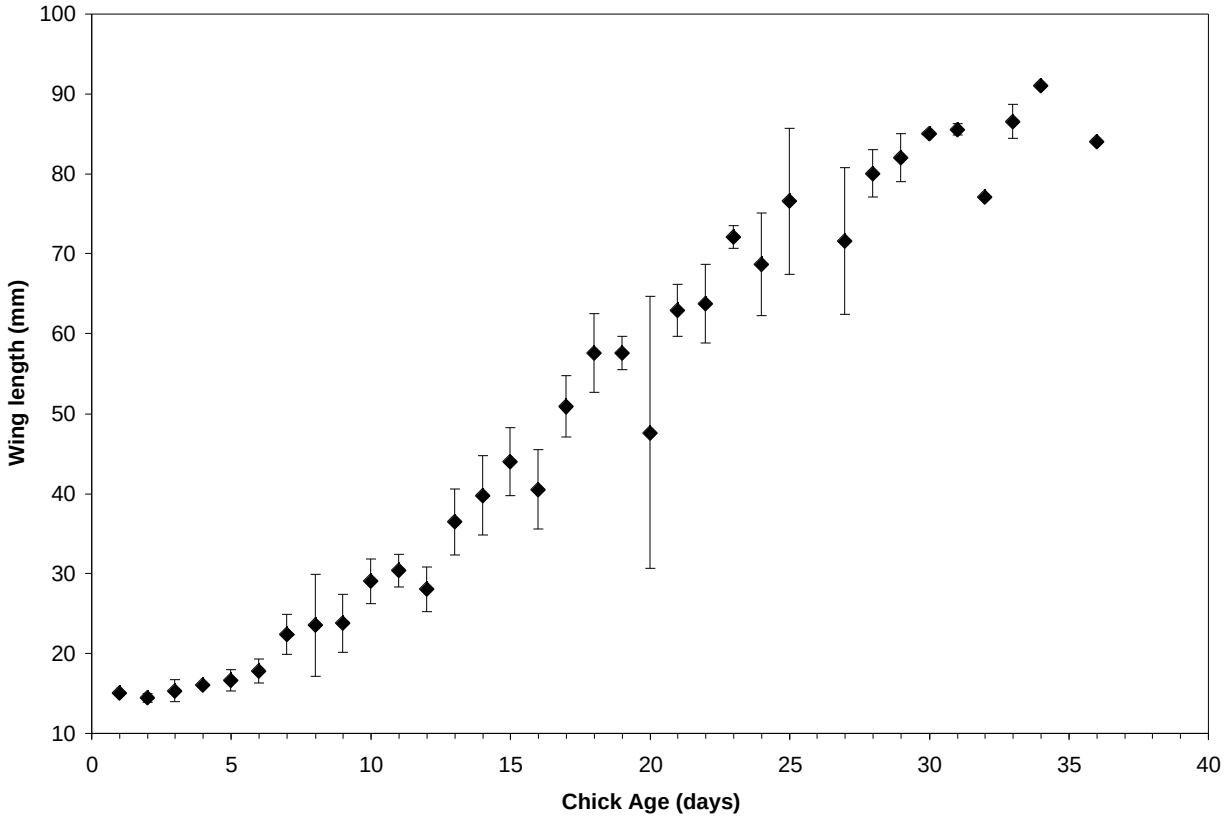

Figure 3 Increase of wing cord length of Least Auklet chicks during the nestling stage at Sirius Point in 2003, the values are the mean with one standard deviation.

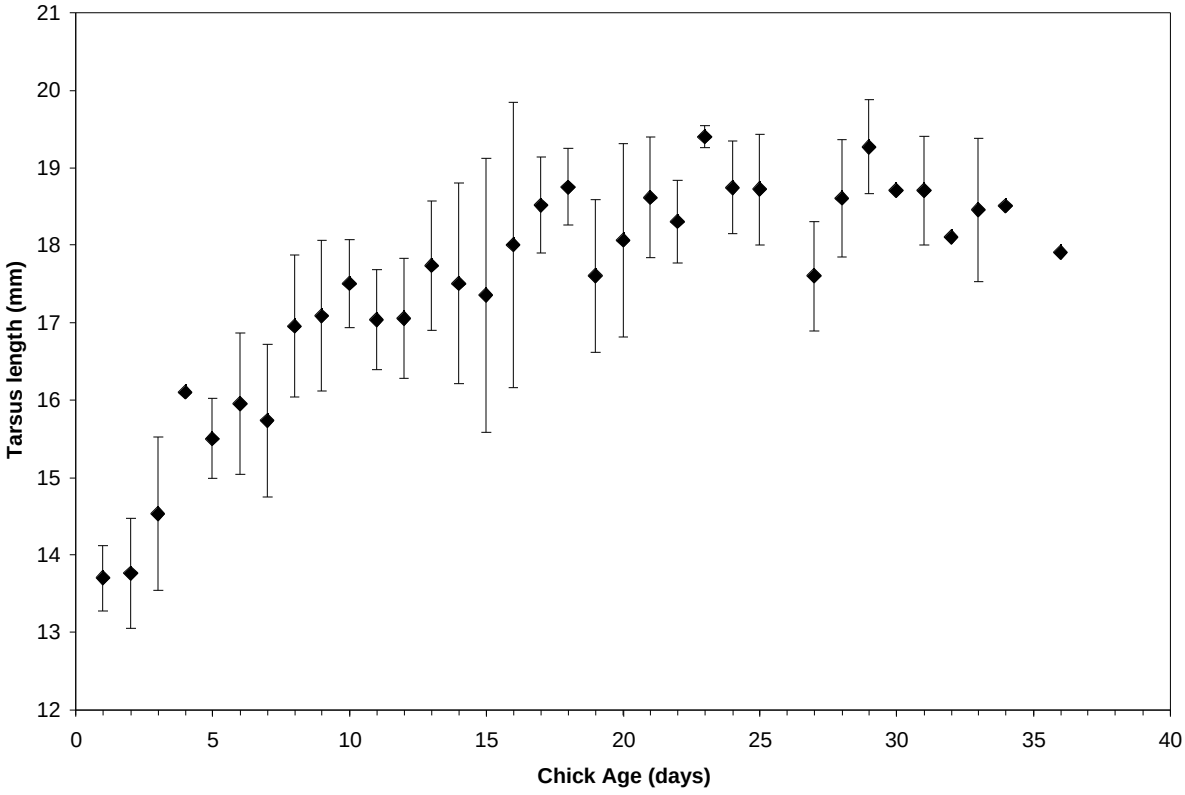

Figure 4 Increase in tarsus length of Least Auklet chicks during the nestling stage at Sirius Point in 2003, values are the mean with one standard deviation.

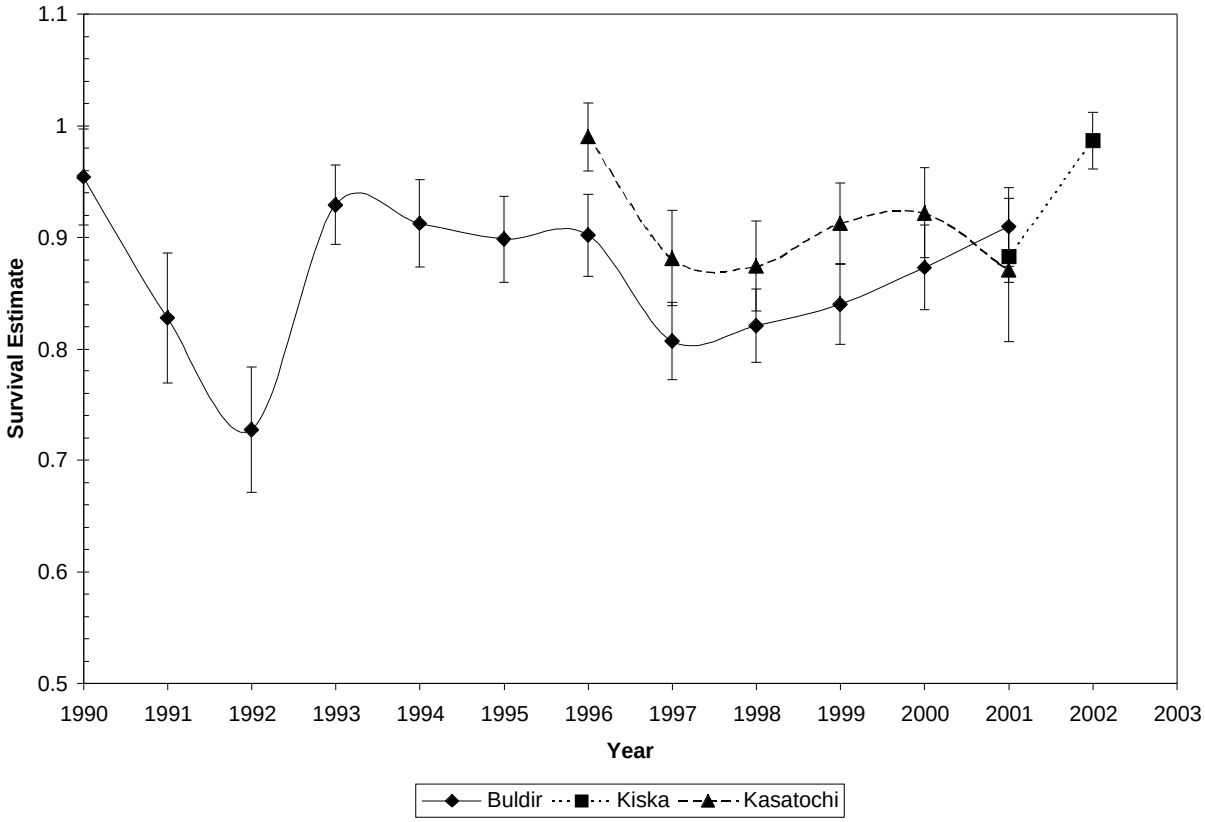

Figure 5 Comparison of the Least Auklet survival estimates (with standard error) from Buldir (1990-2001), Kasatochi (1996-2001) and Kiska (2001-2002).

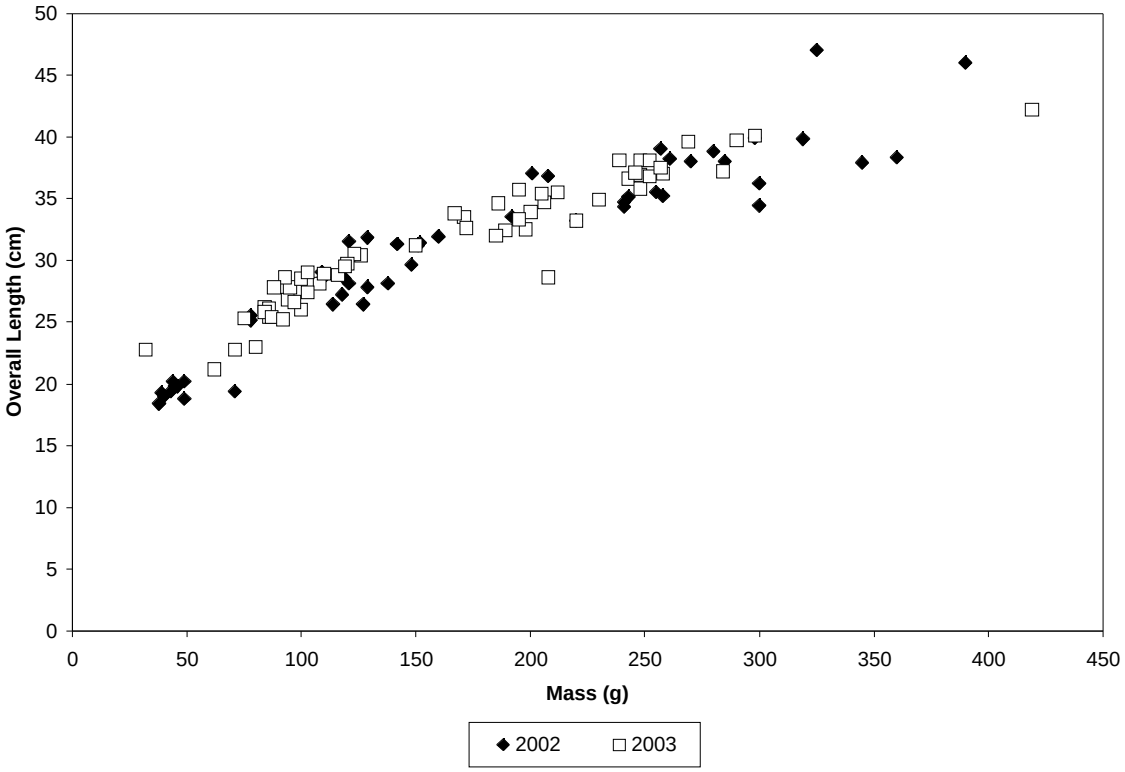

Figure 6 Size distribution of captured Norway Rats on Kiska Island in 2002 and 2003.

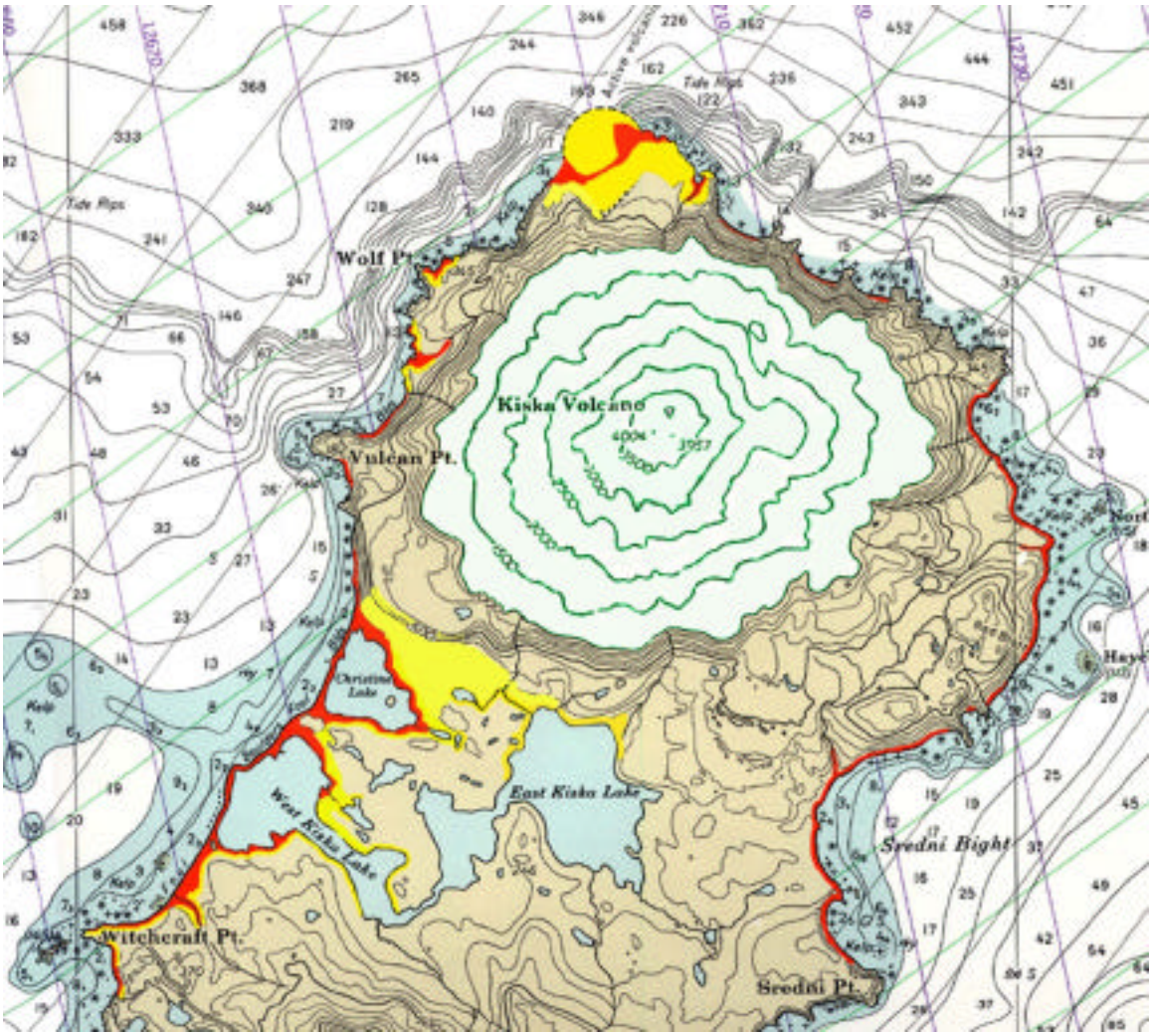

Figure 7 Geographical summer distribution of the Norway Rat on Kiska Island in 2003 where white indicates the absence of rats, yellow the presence of rats in medium to low numbers and red the presence of rats in high numbers.

Appendix 1 Tissue samples taken in 2003for stable isotope analysis.

Location	Species	Date	Number	Tissues Sampled
Sirius Point Auklet	Norway Rat	June 11, 2003	2	Pectoral Muscle, Liver
Colony		June 12, 2003	3	Pectoral Muscle, Liver
		June 17, 2003	5	Pectoral Muscle, Liver
		July 29, 2003	1	Pectoral Muscle, Liver
		July 30, 2003	2	Pectoral Muscle, Liver
		July 31, 2003	1	Pectoral Muscle, Liver
		August 3, 2003	1	Pectoral Muscle, Liver
		August 4, 2003	5	Pectoral Muscle, Liver
	Bull Kelp	August 1, 2003	4	Blade
Christine Lake	Norway Rat	June 16, 2003	10	Pectoral Muscle, Liver
		July 27, 2003	10	Pectoral Muscle, Liver
East Kiska Lake	Norway Rat	June 16, 2003	2	Pectoral Muscle, Liver

Appendix 2 Summary of Norway Rat sign found in 2003.

Date	Location	Comments
June 2, 2003	Sirius Point Auklet Colony (valley between the New Lava and Old Lava Domes)	Cache 1: Rat cache with >20 adult Least Auklets and >10 Least Auklet eggs (the cache was located under a bolder, we could not excavate the entire cache).
Early-mid June	Sirius Point Auklet Colony	Sign is not as abundant as 2002, there is some sign of rats on the colony (we found predated eggs and adults along with droppings). Around camp there is quite a bit of fresh rat sign.
June 13, 2003	Sirius Point Auklet Colony (~50 feet from cache #1)	Cache 2: Rat cache with 8 adult Least Auklets and 11 Least Auklet eggs, all the birds were very decayed.
June 14, 2003	Glen Larry	Extensive digging on the ridge above Glen Larry.
June 14, 2003	Vulcan Point	Extensive digging
June 14, 2003	Cloud Plateau	Digging
June 14-16, 2003	Christine Lake	Abundant rat sign in the intertidal zone, trails visible in the grass (rat abundance appears similar to that in 2002).
June 16, 2003	East Kiska Lake	Footprints found in the sand along the lake's shore
June 16, 2003	Inland between Christine and East Kiska Lakes	Rat sign not abundant
Late June – Early July	Sirius Point Auklet Colony	Abundant rat sign (similar to that in 2002), predated adults, eggs and chicks found all over the New Lava Dome and on the beach in front of Camp.
June 21, 2003	Kiska Volcano	Rat sign found (predated auklets, droppings and digging) from Camp up to Lucie's Lounge (~500-600 ft above sea level).
July 6, 2003	Sirius Point camp	Rat sign (chew marks) found in our fresh food cache (bread) –first time rats have gone after our food
June – August 2003	Old Lava Dome	Rat sign not abundant and hard to find
July –August 2003	Sirius Point camp	Rat droppings and footprints abundant, numerous live rats seen and heard around camp after dark.
August 2003	Sirius Point camp	Predated Crested Auklet adult found behind the weatherport
July 25-26, 2003	Christine Lake	Abundant rat sign on beach, diggings around the purple orchids on the hill that leads to cloud plateau.
July 29, 2003	Sirius Point Auklet Colony (in Camp cove beneath Squid Cave and the New Lava Dome)	Cache 3: Rat cache with 5 Least Auklet adults visible (the cache was located under a bolder and could not be accessed)
Late July – Early August	Bob's Plateau	Lots of predated auklet fledglings

Appendix 3 Birds seen during Sirius Point Study, May 30 – August 7, 2003 (breeding species in bold face).

Common Loon *Gavia immer* Heard and seen at Christine Lake.
Red-throated Loon *Gavia stellata* Heard and seen at Christine Lake.
Laysan Albatross *Diomedea immutabilis* Common off Sirius Point.
Black-footed Albatross *Diomedea nigripes* Uncommon off Sirius Point.
Northern Fulmar *Fulmarus glacialis* Common off Sirius Point.
Short-tailed Shearwater *Puffinus tenuirostris* Uncommon off Sirius Point.
Fork-tailed Storm Petrel *Oceanodroma furcata* Rare off Sirius Point. Heard occasionally at night at camp.
Pelagic Cormorant *Phalacrocorax pelagicus* Uncommon, breeds locally.
Red-faced Cormorant *Phalacrocorax urile* Common, breeds locally.
Canada Goose *Branta canadensis* Flocks flying by Sirius Point regularly, droppings found along route to lakes.
Green-winged Teal *Anas crecca* Common at Christine Lake.
Greater Scaup *Aythia marila* Lots at Christine Lake June and July, several pairs on small ponds.
Bald Eagle *Haliaeetus leucocephalus* Common breeder.
Peregrine Falcon *Falco peregrinus* Common breeder.
Rock Ptarmigan *Lagopus mutus* Common on slopes of volcano.
Rock Sandpiper *Calidris ptilocnemis* Uncommon at Christine Lake.
Parasitic Jaeger *Stercorarius parasiticus* Uncommon off Sirius Point, probably breeds near lakes.
Glaucous-winged Gull *Larus glaucescens* Uncommon at auklet colony, breeds on island in Christine Lake, on beach berm at West Kiska Lake.
Black-legged Kittiwake *Rissa tridactyla* Common, breeds locally.
Red-legged Kittiwake *Rissa brevirostris* Uncommon off Sirius Point.
Thick-billed Murre *Uria lomvia* Uncommon off Sirius Point, breeds locally (Pillar Rock).
Common Murre *Uria aalge*. Uncommon off Sirius Point, breeds locally (Pillar Rock).
Pigeon Guillemot *Cepphus columba* Rare off Sirius Point (breeds locally?)
Parakeet Auklet *Cyclorhynchus psittacula* Uncommon breeder, Sirius Point.
Crested Auklet *Aethia cristatella* Abundant breeder, Sirius Point.
Least Auklet *Aethia pusilla* Abundant breeder, Sirius Point.
Whiskered Auklet *Aethia pygmaea* Rare breeder, Sirius Point, occasionally heard at night near camp.
Horned Puffin *Fratercula corniculata* Uncommon off Sirius Point.
Tufted Puffin *Fratercula cirrhata* Uncommon off Sirius Point (breeding near Wolf Point).
Common Cuckoo *Cuculus canorus* One seen near camp June 18, 2003.
Northern Raven *Corvus corax* Two birds again frequented Sirius Point area throughout the summer.
Winter Wren *Troglodytes troglodytes* Common at Sirius Point, rare along shore of Christine Lake.
Lapland Longspur *Calcarius lapponicus* Common in meadows.
Siberian Flycatcher *Muscicapa sibirica* Two found in the valley between the New Lava and Old Lava Dome June 2, 2003
Snow Bunting *Plectrophenax nivalis* Common in stony habitat.
Gray-crowned Rosy Finch *Leucosticte arctoa* Uncommon at auklet colony.
Hawfinch *Coccothraustes coccothraustes* On seen near Wolf Point, June 16, 2003